FATE OF SUBSURFACE BANDED (KNIFE) AND BROADCAST N APPLIED TO TALL FESCUE (*Festuca arundinacea* Schreb)

by

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INTRODUCTION

Tall fescue (*Festuca arundinacea* Schreb) is the most important cool season grass in Southeast Kansas. It is well adapted to this area and with proper management has a high production potential. Unfortunately inadequate soil fertility often limits fescue growth and eventual production in Southeast Kansas.

Extensive research has been conducted in Kansas comparing fertilizer placement methods for winter wheat (Leikam et.al. 1979; Murphy et.al. 1978). Excellent results were obtained when N and P fertilizers were knifed in the root zone as compared to broadcast applications. The success of this research triggered investigations in Southeast Kansas to compare broadcast and subsurface-banded (knife) applications of N-P-K fertilizers on fescue pastures (Lamond and Moyer 1983). Excellent responses were obtained. The knife method of application gave significantly greater forage production, N concentration in forage and N uptake when compared to the broadcast method. Over a four year period (1979-1982) greater apparent nitrogen recoveries were obtained from knifed methods of N application (table 1). The mean apparent N recovered for the four years was 15% higher in the knifed treatments than in the broadcast treatments.

Researchers in other areas of the U.S. have demonstrated that biological immobilization of N in grasses is a major factor causing low recoveries of N fertilizer. We felt that N immobilization may be reduced with knifed N application since fertilizer is placed in a zone with lesser amounts of decomposing crop residue and decaying roots. With this in mind, we conducted two studies from 1982 to 1983 with the following objectives: first, to determine why N uptake and forage production by tall fescue in Southeast Kansas are higher from knifed than from broadcast applications of N. Second, to follow N transformations under established tall fescue after addition of N using broadcast and knife methods of N application.

TABLE 1: APPARENT N RECOVERIES FROM PAST STUDIES WITH TALL FESCUE IN SOUTHEAST KANSAS

N Rate	Method	Apparent N Recoveries* 1979	1980	1981	1982	x
kg/ha		%				
168	knife	63	43	41	65	53
168	b'cast	42	30	28	53	38

*App. N rec.= $\frac{\text{kg N in fert forage - kg N in unfert forage}}{\text{kg N applied}}$ X 100

CHAPTER 1

REVIEW OF LITERATURE

The supply of N in grasses often limits production since soils usually do not contain sufficient amounts of available N for maximum yields. A soil may contain large amounts of combined N in organic matter, but the amounts available for uptake by the forage are usually low. Therefore, some source of N fertilizer must be used to maximize forage production.

Since grasses are so responsive to fertilizer N, many investigations have been carried out to study N transformations in these ecosystems. It is the aim of this review to summarize some important studies conducted in temperate regions.

I. FORAGE RECOVERY OF FERTILIZER NITROGEN

The percentage of applied N recovered in forage grasses varies greatly. Burton and De Vane (1952), reported recoveries of N in bermudagrass of 42, 60, 66 and 64% for rates of 56, 112, 224 and 448 kg of N, respectively. Hallock, Brown and Blaser (1965) reported recoveries of 65% on fescue. On the other hand only 25% of the applied N was accounted for in plant tops of bromegrass (Power 1967).

A major factor affecting the percentage recovery of N is the rate of application (Power 1972). Other factors are species of

grass, temperature, source of N, time interval between application and harvesting, soil type and climate. The soil N and organic matter content, fertilizer placement method used, soil microbial activity and the amount of fertilizer N utilized by the root system are the main determining factors and will be discussed in more detail.

A. Influence of Soil N and Organic Matter Content

When arable soils are sown to grass, contents of O.M. and N increase as long as the sward remains unploughed. Roots and herbage are great contributors to the soil O.M. as well as animal excreta on grazed swards (Whitehead 1970).

The N content of grass herbage appears to vary from about 0.7 to about 3.4% depending upon the amount of N supplied as well as the grass species (Whitehead 1970). Assuming an average N content of 1.5%, herbage production of 6,000 kg/ha would contribute 90 kg N/ha to the soil organic matter, assuming none was removed. If the forage was utilized for hay this amount of N would be removed from the sward.

Studies conducted by Baker and Garwood (1959), demonstrated that the minimum annual dry matter contribution of roots in a productive sward could be up to 3,400 kg/ha. The N content of grass roots is normally 1.0 - 1.8%. Thus, assuming an annual root turnover of 3,400 kg/ha and a N content of 1.5%, the soil O.M. would receive 51 kg N/ha from this source. In a study conducted by Power (1967), 75 kg of mineral N/ha was formed when unfertilized plots were left fallow, while the N content of tops of unfertilized grass was about 15 kg/ha. From these results, Power suggested that most of the N made available in unfertilized

grassland during a season may come from the decomposition of fresh root material.

The estimates given above are for productive grass swards in lowland areas and will probably be lower in less productive areas. Neverthelesss, grass swards supply great quantities of residues to the soil due to their extensive root system and forage production. The decaying of these materials contribute to the soil organic N content.

The decomposition of organic materials with a wide C:N ratio will result in the immobilization of N, whereas materials with a low C:N ratio will release mineral N to the soil. Immobilization of N in soil O.M. is likely to occur when the C:N ratio of the material undergoing decomposition is higher than 30:1 and mineralization when the ratio is less than 20 or 25:1 (Alexander 1977).

B. Influence of Microbial Immobilization

Immobilization refers to the microbiological transformation of inorganic nitrogen (NH_4^+, NH_3, NO_3^-, NO_2^-) into the organic state (Jansson and Persson 1982). Soil organisms assimilate inorganic N compounds and transform them into organic N constituents of their cells and tissues. Inorganic N is also transformed into the organic state when assimilated by plants. Plant assimilation is considered a variant of immobilization but it is usually not included under the definition of immobilization.

Immobilization competes with plant N uptake and has been

considered a major factor causing low recoveries of applied N in grasses (Kissel and Smith 1978; Kissel, Bartek and Zapotek 1979; Power and Alessi 1971; Power 1972; Power 1981). Gerretsen (1950) showed that microorganisms may monopolize up to 50% of the total available nitrogen and compete with plants to such an extent that plant growth is limited.

Recent work has indicated that the quantity of nitrogen immobilized depends not only on the C:N ratio and amount of organic material which may be undergoing decomposition, but also on the nature of the nitrogen source, the soil pH, organic matter level and other soil properties as well.

Many researchers have demonstrated a preferential utilization of ammonium N over nitrate N by soil organisms. Jansson et.al. (1955), found that when ammonium and nitrate ions were supplied in equal quantities as ammonium nitrate, organisms decomposing oat straw utilized the ammonium ion almost exclusively. In later work, Jansson (1958) concluded that nitrate is not normally subject to immobilization. Similar observations were made by Simpson and Freney (1967). In their investigation, ammonium and nitrate labeled with ^{15}N were added separately to three soils representing different stages of organic matter accumulation under pasture. The fate of the labeled N was determined after six weeks, and again following 29 weeks in the presence and absence of ryegrass plants. The results indicated that the labeled ammonium was immobilized rapidly while the nitrate was immobilized much more slowly. Thus recovery of labeled nitrate nitrogen by the plants was generally greater than that of ammonium.

Soil nitrifiers will compete with heterotrophic N immobilizing flora for ammonium nitrogen (Frederick and Broadbent 1966). The amount of nitrogen immobilized during a given period will then depend upon the activity of soil nitrifiers since after conversion to nitrate, fertilizer nitrogen has less propensity to be immobilized. Broadbent and Tyler (1962) demonstrated that the competition between soil nitrifiers and the heterotrophic immobilizing flora can vary according to the nature of the soil. In working with a fine textured soil, the addition of ammonium sulfate tagged with ^{15}N plus straw enhanced the competition between the nitrifying bacteria and the immobilizing flora for the available nitrogen since a substantial part of the tracer nitrogen added appeared in the soil nitrate fraction. This was not observed in the coarse textured soil used in the experiment. In their greenhouse experiments competition for added tracer nitrogen between a growing crop and the immobilizing flora emphasized preferential utilization of ammonium nitrogen by soil microorganisms and of nitrate nitrogen by the crop.

In an experiment dealing with the effect of temperature on mineralization of nitrogen, Jansson (1958) reported that increasing the temperature from 15 to 30 C greatly stimulated the mineralization process and at the same time the immobilization of N was little affected. Broadbent (1966) found immobilization to be much slower at 7 C than at 24 or 32 C, but the total quantity of fertilizer N immobilized at the end of the experiment was nearly the same at all three temperatures. In a study conducted by Kissel et. al. (1977) calcium nitrate tagged with ^{15}N was

applied at a high rate (328 kg N/ha) to field microplots where grain sorghum was planted. The quantity of nitrogen immobilized throughout the growing season was determined. The amounts immobilized were quite small during the first five weeks following fertilizer application but rapidly increased after that time. The maximum immobilization was equivalent to about 19% of the N applied in the study. The increase in the rate of immobilization began only after the soil temperature at the 15 cm depth was 22 C or above and was most rapid when temperatures were about 26 to 27 C.

Numerous experiments have been conducted to evaluate the residual effects of nitrogen fertilizers. Rapid immobilization of added N in soil where ryegrass was grown was reported by Tyler and Broadbent (1958). The addition of untagged fertilizer after the second cutting did not stimulate the release of this immobilized nitrogen. In experiments where straw was added Broadbent and Tyler (1962) also concluded that immobilized nitrogen resists mineralization for long periods of time. In both experiments Tyler and Broadbent concluded that the decrease in availability of recently immobilized nitrogen is a gradual and continuous process probably because the nitrogenous compounds are constantly being converted into compounds of greater biological stability. This was also found in a 2-year experiment reported by Broadbent and Nakashima (1965). Eight cuttings of sudangrass were taken during this period. The results obtained showed that plant uptake of nitrogen from tagged ammonium sulfate was largely taking place in the first one or two cuttings, with very little activity therefter. The quantity of fertilizer nitrogen

recovered was greater when straw was absent. Tyler and Broadbent (1958) measured nitrogen uptake by four ryegrass cuttings from aqueous ammonia, ammonium sulfate and ammonium nitrate in pot experiments. After 23 weeks of cropping no measurable amounts of inorganic nitrogen remained in the soils, but fertilizer nitrogen present in the organic form varied from 24 to 41 percent of the total added depending on the soil type and the source of nitrogen used.

Many previous studies on ^{15}N labeled residual nitrogen forms have been conducted in the greenhouse, laboratory and field. Smith et. al. (1978) characterized the residual nitrogen fertilizer of a clay soil where a single season nitrogen balance study was conducted with coastal bermudagrass (Kissel and Smith 1978). The results obtained indicated that 96 % of the residual fertilizer nitrogen was present in the organic form whereas only 3 % was present in the inorganic form. The organic N forms were characterized into three broad chemical fractions following HCl hydrolysis: fraction 1 is distillable, acid soluble NH_4-N which includes ammonia N released during hydrolysis, amide N and amino sugar N; fraction 2 is non-distillable, acid soluble N which includes amino acid N; fraction 3 includes acid insoluble humin and the N of the insoluble residue. Most of the residual N was found in fraction 2. Approximately 73 % of the total residual N was found as aminoacid N while only 22 and 5 percent were found in the first and third fractions, respectively. The availability of this nitrogen was measured by determining the nitrogen availability ratio utilizing the following formula:

$$\text{N availability ratio} = \frac{\text{residual N mineralized/total N mineralized}}{\text{residual N in soil/ total N in soil}}$$

A ratio of unity means the residual and indigenous N are identically available, whereas a ratio greater than one means the residual N is more available and viceversa. This ratio was determined for a period of 24 weeks after the soil was sampled. Results showed the ratio to decrease with time but never reached unity. Therefore, the residual N was considerably more susceptible to mineralization than the soil N. This was an indication that equilibration with the most stable forms of soil N had not yet occurred.

Similar results were obtained by Allen et.al. (1973) from studies in field plots previously ammended with ^{15}N labeled urea and where a sorghum-sudan hybrid crop was grown. They found up to 40% of the applied nitrogen to be present in the soil after the first growing season, about half of which still remained after five years. Essentially all the fertilizer-derived N (97%) occurred in organic combinations; only a small fraction (3%) was accounted for in the inorganic forms, chiefly as fixed ammonium. Most of the fertilizer N remaining after the first growing season occurred as amino acids and amino sugars; on the other hand lower percentages occurred in acid insoluble forms, acid hydrolyzable organic NH_3, and as unidentified acid soluble nitrogen. During the subsequent four years considerable humification took place with transformation of aminoacid and amino sugar nitrogen to more resistant humus forms.

C. Influence of Fertilizer Placement Method

Most of the research involving fertilizer placement methods has been conducted with crops other than established forage grasses. Extensive field studies have been conducted in Kansas comparing fertilizer placement methods for winter wheat (Leikam et.al. 1983; Murphy et.al.1978). Excellent results were obtained with subsurface-banded (knife) applications of nitrogen and phosphorus. Since the growth and development of winter wheat coincides closely with that of the cool season grasses, investigations were initiated to compare broadcast and subsurface banded applications of N-P-K fertilizers on established tall fescue (Lamond and Moyer 1983). They found knifed fertilization to be superior to broadcast applications of fertilizer and noted increased forage yields, N content, N uptake, K uptake and sometimes P concentrations and P uptake from knife applications. The superiority of the knifed applications was due mainly to better N utilization. Compared with the broadcast method, knifing N significantly increased forage production by 24%.

Research conducted by Schou and Tesar (1977) involved some nitrogen-source work where anhydrous ammonia was compared to ammonium nitrate in permanent forage grasses. Due to it's nature, anhydrous ammonia was injected 13 cm deep while ammonium nitrate was surface broadcast. Five grass species were utilized in this experiment: bromegrass, reed canarygrass, tall fescue, Kentucky bluegrass and orchadgrass. Three separate grass cuttings were made during 1971 and another three in 1972. In general, during 1971 most of the greater yields from the AN

fertilized grass occurred in the first two cuttings. Third cutting yields were greatest with AA. There was a greater soil residual N effect from AA because less of the AA was used in the first two cuttings as compared to AN as well as the factor of time required to convert ammonia nitrogen to nitrate nitrogen. Because of this residual nitrogen grasses yielded 20 to 50 percent more when fertilized with AA than with AN during the second year.

Greater yields and nitrogen uptake were also obtained with sudangrass when knifing fertilizer N (Legg and Allison 1959). In this experiment ammonium sulfate tagged with ^{15}N was either knifed or mixed into the soil surface. The objective was to determine the availability of fertilizer nitrogen to plants when applied to soils with high fixation capacities. The differences in nitrogen availability between the two methods could not be attributed entirely to ammonium fixation. They concluded that microbial immobilization of nitrogen may have been enhanced by mixing the fertilizer into the soil thus making this nitrogen unavailable for plant uptake. Tomar and Soper (1981) evaluated the effect of fertilizer N placement on the efficiency and immobilization of applied N. As obtained by Legg and Allison with sudangrass, barley yields and N uptake in this experiment were also greater from banded N than from broadcast N. They attributed this superiority to the reduced immobilization in banded N treatments. Immobilization was enhanced in broadcast treatment plots by the addition of organic matter.

In general, these and other studies seem to agree that immobilization of N by soil microorganisms will take place at

varying degrees depending upon the method of N placement used. This in turn will affect the amount of N recovered by the crop.

D. <u>Influence of the Amount of N Utilized by the Root System</u>

Grasses are known to have a very extensive root system. In working with several grass species Power (1980) found that generally the root biomass was 10 to 20 times greater than the annual above-ground dry matter production depending upon the grass species studied and the amount of N applied. Kissel and Smith (1978) reported root dry matter weights of 12,771 kg/ha for coastal bermudagrass while up to 24,310 kg/ha of root material were reported by Black and Wight (1979) in working with a native grassland herbage. Other researchers have reported similar root yields (Blue 1970; Power 1972; Power and Alessi 1971; Ogus and Fox 1970).

By virtue of their large mass and low N content, grass roots may utilize up to several hundred kilograms of fertilizer N/ha (Power 1968). Power and Alessi (1971) recognized this utilization of N by roots as an important factor contributing to the low amount recovered in grass tops. They concluded that in order to obtain maximum top growth, this N root utilizing capacity must be satisfied, a process which requires not only high fertilizer N rates but also a long period of time (several years). Blue (1970) found that N recovery by bahiagrass increased from 43% in 1963 to 61% in 1967 at the 112 kg/ha/year rate and from 45 to 71% over the same period of time when N was applied at the 224 kg/ha/year rate. Total root and stolon yields at the end of 1967 were 14,270, 19,160, and 18,190 kg/ha containing 0.79, 0.95 and

1.35 percent N at the 0, 112, and 224 kg N/ha rates respectively. Blue attributed the higher N recovery to the rapid accumulation of stolons and roots at the 224 kg N rate as well as to the immobilization of N in stolons and roots during the first few years of the experiment. Once the underground organ requirement was met, more N was available for top growth. Similar results were obtained by Power (1972) in his work with mixed prairiegrasses. Up to 200 kg of fertilizer N/ha were immobilized the first year by the combination of grass roots, soil organic matter and fixed ammonium combined. The amount of N immobilized increased to about 350 kg after three to four years and remained constant thereafter. About half the immobilized N was found to be contained in the grass roots at the termination of the experiment, which shows their importance as potential N consumers. The results obtained by Power clearly indicate that, with time, the use of high N rates in grasses can saturate the capacity of the soil-plant system to immobilize N. Only then can N may be eliminated as a growth limiting factor, thus enabling maximum N utilization by the forage.

Mineralization rates of N from various plant residues have been reported. However, there is limited information related to the mineralization of nitrogen from grass roots. Power (1967, 1968, 1981) conducted several studies attempting to measure the availability of this nitrogen. In one of his studies (1967) the net mineralization rate of previously fertilized bromegrass roots was determined by incubating them with soil for a 10 week period. The data obtained indicated a net immobilization of soil mineral nitrogen when unfertilized roots were added, whereas a net

mineralization occurred when fertilized roots were added. The amount immobilized or mineralized was proportional to the amount of root material applied. Power suggested that grass root material follows essentially the same pattern of decomposition as any other plant tissue. Mineralization of N contained in the root material would then be controlled primarily by the N content (C:N ratio) of the roots.

The total amounts of nitrogen mineralized in this last study will divert from those found in a grassland system but could be representative of such a system left in fallow. In a field study, Power (1968) found 75 kg /ha of mineral N produced when unfertilized bromegrass plots were left in fallow, the N content of tops of unfertilized grass being about 15 kg/ha (no NO_3 accumulated in the soil). Assuming these figures represent the amounts mineralized in the fallow and grassed plots respectively, then mineralization occurred five times faster in fallow plots than in grass plots. In later work (1981), Power estimated the amounts of fertilizer N which mineralized from grass roots in a native mixed prairie previously fertilized with high and low amounts of nitrogen. From 0 up to about 30% of the fertilizer N utilized by the roots (0 to 12 % of the total fertilizer N applied) was accounted for in plant tops. When residual plant growth responses ceased, approximately six to eight years later, still a significant amount of fertilizer N remained in the root system.

There is some evidence that suggests that mineralization of N from soil organic matter is reduced by the presence of grass

roots (Munro 1966 and Theron 1963). Woldendrop et.al. (1965) has shown that the respiration of living roots appreciably reduces soil oxygen levels. The high root density in grasslands as compared to most arable soils would therefore be a contributing factor in the slower rate of organic matter decomposition. This in turn may partially explain the higher level of organic matter and nitrogen encountered in grasslands as compared to arable soils.

II. TAGGED AND NONTAGGED NITROGEN BALANCE EXPERIMENTS IN GRASSLANDS

A. Experiments Using Tagged Nitrogen

The use of the stable N isotope ^{15}N in many laboratory, greenhouse and field experiments has provided considerable insight into the understanding of transformations of N in grassland soils. Much of the early work has been summarized by Allison (1966) and Martin and Skyring (1962).

Perhaps one of the earliest nitrogen balance experiments using tagged nitrogen in grasses was that conducted by McVicar et.al. (1950). Using ammonium sulfate as the nitrogen source and sudangrass as the crop they accounted for 85 to 97 percent of the added nitrogen at the end of their study. From 38 to 47 percent of the added nitrogen was recovered in the plant leaf and root tissues. The lowest recovery rates were associated with a low level of soil organic matter and high level of nitrogen. Walker et.al. (1956) reported losses of 30 percent of the applied N working with ryegrass. Their results indicated slightly higher losses from tagged potassium nitrate than from tagged ammonium

sulfate. In both cases some labeled N was found as soil organic nitrogen. It was assumed that most of the N lost was due to denitrification since they could not account for all the tagged N applied. Experiments by Tyler and Broadbent (1959) in which tagged ammonium nitrogen was added to two soils and a crop of ryegrass grown gave the highest recovery rates of nitrogen from ammonium sulfate and the lowest from ammonium hydroxide with ammonium nitrate intermediate. Tyler and Broadbent (1962) also reported recovery data from pot experiments using a cropped and uncropped sandy loam soil with and without additions of straw. Their results showed the highest recovery of N from cropped soils, the tagged ammonium sulfate giving somewhat higher values than potassium nitrate. The addition of straw resulted in higher N recovery for both cropped and uncropped soils regardless of the source of N utilized. In the majority of the pots much of the added N was either rapidly immobilized by the added straw or assimilated by the grass. Recoveries of N by the grass were lowest when straw was added. During a long term experiment Broadbent and Nakashima (1965) obtained an average recovery of 68 % of the added tagged nitrogen, but in this case the recoveries were slightly lower in the presence of straw than otherwise. Whether straw was added or not the quantity of residual tracer N in the soil organic fraction was appreciable. Nevertheless, the addition of straw enhanced immobilization to a greater extent resulting in lower amounts of fertilizer N recovered by the grass. The immobilized N seemed to become progressively less available since even after two years of continuous cropping no

significant release was evident. Fertilizer N utilization by the crop was improved by growing plants during that period immediately following fertilizer applications; whereas a delay in planting resulted in a poorer recovery of N by the crop. In this investigation ammonium and nitrate labeled nitrogen were added separately to three soils representing different stages of organic matter accumulation under pasture. The results obtained showed that the labeled ammonium was immobilized rapidly while the nitrate reacted much more slowly. Thus recovery of labeled nitrate nitrogen by the plants was generally greater than that of ammonium nitrogen.

A few Lysimeter studies involving the use of ^{15}N have been conducted in the field to determine the fate of applied nitrogen under grasses. Jones et. al. (1977) conducted such a study involving the use of of ammonium sulfate labeled with tagged ammonium chloride applied to grass growing in Lysimeters. After three years of annual fertilization 59 % of the N applied was found in the forage, 24% remained in the soil and roots, 3% leached, and 14% was not detected (presumed gaseous loss). In general, there seemed to be a modest gaseous loss of nitrogen which may partially explain the low recoveries of N obtained in the forage, but the amounts of nitrogen remaining in the soil as organic nitrogen or root nitrogen were not determined separately. Therefore, their contribution to the low forage N recovery was not established. In a study conducted by Kissel and Smith (1978) tagged nitrogen was applied to coastal bermudagrass; the roots were able to immobilize up to 12 % of the fertilizer N applied while as much as 22 % was found as organic nitrogen at the end of

the growing season. Fertilizer N uptake by the forage amounted to 49% of the applied N in this study. Only 17 % of the residual nitrogen (root and organic soil N) was recovered in the forage the following year. In a long term study with crested wheatgrass Power and Legg (1984) reported as much as 29 to 49 % of the applied N present as organic N and 15% as root N after the first growing season.

B. Experiments Using Non Tagged Nitrogen

A few experiments with non-tagged N have been conducted to better understand the transformations and eventual fate of applied N in grasses. Power and his coworkers (1967, 1972, 1973, 1980, 1981) have conducted much of the recent research in this area. Results obtained from these studies are listed in table 1. In general, most of his experiments showed low recoveries of fertilizer N by the forage. Low soil inorganic N contents were also observed except when bromegrass was grown under dryland conditions (Power 1967). Roots seem to account for a large portion of the fertilizer N not recovered in tops. In some instances this was true even six years after fertilization had ceased (Power 1981). The high percentages of N not accounted for were usually assumed to be immobilized. Research conducted by Black and Wight (1979) with a native grassland also demonstrated the high potential that roots have to immobilize relatively large amounts of applied N. In this study as much as 20,700 kg/ha of root material were reported from the upper 30 cm of soil. With such an extensive root system we should anticipate large amounts of fertilizer N being utilized by these roots. Approximately

34% of the applied N was accounted for in the root system in this experiment while 48% was accounted for in plant tops.

TABLE 1: N BALANCE EXPERIMENTS CONDUCTED BY J.F. POWER IN GRASSLANDS

Reference	Type of grass	Years of study	Total N applied (kg/ha)	Fertilizer N in: Tops	Roots	Soil inorg	Not Found
				------------	%	------------	
Power (1967)	brome/ irrigated	2	500	40	25-35	5-10	20
Power (1967)	brome/ dryland	2	500	25	10-25	25-65	0-20
Power (1972)	native	6	540	27	32	11	30
Power et.al. (1973)	brome	4	440	75	*	0	23
Power (1980)	brome	6	420	30	15	20	35
Power (1981)	native	6	540	28	26	12	34

* not reported.

CHAPTER 2

FATE OF SUBSURFACE-BANDED AND BROADCAST ^{15}N APPLIED TO TALL FESCUE

Abstract

The purpose of this study was to determine why N uptake and forage production by tall fescue in Southeast Kansas are greater from subsurface banded than from broadcast N applications. The fate of N fertilizer applied to fescue either broadcast or banded in 1982 was determined using ^{15}N tagged UAN solution and measuring various components of the N balance. Plant uptake of residual N was measured during 1983. Fifty-eight percent of the applied N was recovered in harvested forage in 1982 where N was knifed; while only 37% was recovered in broadcast treatments. The amounts of N remaining in the soil as residual N at the end of 1982 amounted to 34% and 39% for broadcast and knifed treatments, respectively. Most of this residual N was not available the following year since only about 6 to 7% was recovered in the forage. About 6% of the knifed N was unaccounted for indicating that gaseous losses (denitrification and ammonia volatilization) were no more than 6% of the applied N; while up to 29% of the broadcast N was unaccounted for, indicating probable significant gaseous losses. Similar results were obtained from microplots removed during 1983.

In general, results obtained in this study suggest that the improved efficiency of knifed N over broadcast N observed in

Southeast Kansas in past years may be explained by the reduced gaseous N losses obtained in this treatment.

Introduction

Several factors have been found to affect the amount of fertilizer N recovered in forage grasses. A major factor affecting the efficient use of N fertilizer by forage grasses is the rate of application (Power 1972). Microbial immobilization of N competes with plant N uptake and has been considered a major factor causing low recoveries of applied N by grasses (Kissel and Smith 1978; Kissel, Bartek and Zapotek 1979; Power and Alessi 1971; Power 1972; Power 1981). Another cause of low N efficiency is uptake and storage in plant roots. By virtue of their large mass and low N content grass roots may utilize up to several hundred kilograms of fertilizer N/ha (Power 1968). Power and Alessi (1971) recognized this utilization of N by roots as an important factor contributing to low N recoveries by grass tops. In other experiments the low recoveries of N have been attributed to gaseous losses by denitrification and/or ammonia volatilization (Simpson and Freney 1967; Power 1980; Power et.al.1973).

Research has been conducted in Southeast Kansas to compare fertilizer placement methods on tall fescue (Lamond and Moyer 1983). Knifed (subsurface band) fertilization significantly increased fescue forage yields and N uptake compared to broadcast fertilization. These results led us to believe that N volatilization and/or immobilization by soil microorganisms may

have been less where N was knifed causing the higher N recoveries observed in knifed treatments. With this in mind we conducted a ^{15}N balance study to determine why N uptake and forage production by tall fescue in Southeast Kansas are higher from knifed than from broadcast N applications.

Materials and Methods

The study was conducted in Labette county, Kansas. The research site had been in tall fescue for over ten years and had received very little N fertilization previously. The soil is a Parsons silty clay loam (mollic Albaqualf, fine, mixed, thermic) with 12 ug/g available P, 110 ug/g exchangeable K^+ and 4.5 % O.M. in the top 15 cm of soil. The soil has a C.E.C. of about 200 mmol(+)kg-1 and a pH that may vary from 6.5 to 7.5.

During March 1982 four open-ended steel boxes, each with an area of 0.14 m^2, were forced into the soil to a depth of 44cm until their tops extended about 2cm above the soil surface. These enclosed areas were used as microplots for the study.

Fertilizer N was applied to all four microplots at a rate of 112 kg N/ha. The fertilizer material was applied broadcast to two microplots and in the remaining two the fertilizer was banded at a depth of 15 cm. The source of N was UAN (28% N solution) containing 28.84 atom percent N^{15}. Phosphorus was broadcast on each microplot as triple superphosphate at a rate of 20 kg P/ha. An adjacent area was not fertilized with N but received the same rate of P as each microplot. This area was used as a control (check plot).

During 1982 all four microplots and the control were harvested three times. On November 20 two microplots (one of each treatment) were removed from the field. The other two microplots remained in the field (no fertilizer was applied in 1983) to measure residual N uptake by the forage until the microplots were removed on July 1983.

After removing each respective microplot from the field, we removed all the soil in increments to a depth of 60 cm. Conventional soil samples were taken from 60 to 90 cm in one increment with a core sampler and compositing 6 cores from the center of each microplot.

Soil removed from microplots during 1982 was immediately air dried at a temperature of 45 C, finely ground and mixed uniformly for 20 minutes in a cement mixer. Approximately 400 g subsamples were taken from each layer and stored in sealed plastic vials until analyzed. About 100 g of soil were extracted with 2N KCl using a Buchner funnel. The NO_3^--N and NH_4^+-N in the filtered extracts were measured colorimetrically on a dual-channel Technicon autoanalyzer. Soil samples were digested using the salicylic acid-thiosulfate procedure described by Bremner and Mulvaney (1983). Total N was determined in the digest by steam distillation using the procedure described by Bremner and Keeney (1965). Plant material harvested during 1982 was dried in a forced-air oven at 65 C, weighed, ground in a Wiley mill and stored in sealed plastic vials for later N determination. Samples were digested using the same procedure as for soil and N measured in the autoanalyzer.

In 1983, all the soil was removed from the same depths of the microplots as in 1982 and separately placed in a 200 liter steel container to homogenize the samples and separate plant roots from the mixture. Distilled water was added to give a soil/water ratio of about 2:1. The soil and water were mixed with a stirring mechanism attached to an electrical drill until the soil-water mixture was a homogenous suspension. Roots were removed from the mixture during mixing, washed, dried, weighed and then ground finely for analysis. The soil mixture was then sampled with large beakers while being stirred. Duplicate samples were collected to determine the soil:water ratio and other duplicate samples were extracted immediately after adding dry KCl and analyzed for $NO_3^- + NH_4^+$-N. Total soil N was also determined on KCl extracted samples. Roots were air dried at 65 C, weighed, ground and analyzed for N.

Once the N concentration of all soil and plant samples was known, an aliquot containing 1 mg N was distilled using procedures described by Bremner and Keeney (1965). The NH_3 distilled was collected in a weak HCl solution. This solution was subsequently dried and analyzed for N isotope ratio.

Results And Discussion

Microplots removed in 1982

The mean production of fescue forage during 1982 is shown in table 1. There was a moderate response to the application of N at the first harvest (May 18) with both methods of application giving nearly equal yields. Greater yields were obtained at the

TABLE 1. DRY MATTER PRODUCTION OF TALL FESCUE AT EACH OF THREE HARVESTS ON THE MICROPLOTS AND AN ADJACENT CHECK PLOT DURING 1982.

	MEAN DRY MATTER PRODUCTION		
Harvest date	Method of N application		Unfertilized
	Broadcast	Knife	
	--------kg/ha--------		
May 18	4082	4023	3005
August 6	2751	3525	2737
November 20	2481	2830	2153
TOTAL	9314	10378	7895

last two harvests where N was banded resulting in 10% greater total forage production in 1982 from the banded N.

Fertilizer N uptake by tall fescue during 1982 is shown in table 2. Fertilizer N uptake was 25 kg/ha greater at the first harvest when N was banded. At the second and third harvests N recoveries were about the same for both methods of application. For all three harvests, nitrogen uptake by forage from banded nitrogen was 65 kg N/ha (58% of the fertilzer N) while only 41.6 kg N/ha (37%) was taken up in the broadcast treatment.

A large part of the fertilizer N not recovered in harvested forage during 1982 remained in the soil as residual N (table 3). A total of 38.1 kg N/ha was present as residual N (root, immobilized and inorganic N) in the broadcast treatment; of which 23.5 kg N/ha were in the 0-5 cm depth. Below this depth concentrations of residual N were relatively uniform to a depth of 60 cm. In the knife treatment, 44.1 kg fertilizer N/ha were found as residual N. Most of this N was present near the depth of fertilizer placement (10.4 kg residual N/ha or 24% of the total residual N). Below the 20 cm depth residual N decreased considerably.

Only 1.9 kg/ha of inorganic N fertilizer (1.7% of the applied N) was found in the soil profile where N was broadcast; while 5 kg N/ha (4.5% of the applied N) were found in the knife treatment. Rapid depletion of soil inorganic N levels after N fertilization has been reported in many investigations conducted with grasses. In a study conducted by Kissel et.al. (1979) NO_3-N from fertilizer, applied to coastal bermudagrass at 504 kg N/ha, had largely disappeared by midseason. In an earlier study using

Table 2. MEAN FERTILIZER NITROGEN UPTAKE BY TALL FESCUE AT EACH OF THREE HARVESTS ON ALL FOUR MICROPLOTS DURING 1982.

Harvest date	Method of N Application		
	Broadcast	Knife	Difference
	----------------kg N/ha----------------		
18 May	32.5	57.2	-24.7
6 August	6.2	5.2	1.0
20 November	2.9	2.6	0.3
Total	41.6	65.0	-23.4

Table 3. FERTILIZER N REMAINING IN THE SOIL AFTER FINAL HARVEST IN NOVEMBER 1982.

	Broadcast N			Knifed N		
Depth	Root & Immob N	Inorg N	Total Residual N	Root & Immob N	Inorg N	Total Residual N
cm	----------	----------	----------	kg/ha	----------	----------
0-5	21.9	1.6	23.5	8.8	3.0	11.8
5-10	4.8	0.2	5.0	8.2	1.6	9.8
10-20	3.8	0.1	3.9	10.0	0.4	10.4
20-30	3.1	0.0	3.1	8.1	0.0	8.1
30-60	2.6	0.0	2.6	3.3	0.0	3.3
60-90	0.0	0.0	0.0	0.7	0.0	0.7
Total	36.2	1.9	38.1	39.1	5.0	44.1

^{15}N, Kissel and Smith (1978) reported that low N use efficiency by coastal bermudagrass was largely due to biological immobilization of N.

Since roots were not removed from the soil mass in the microplots removed in 1982 we were unable to estimate separately the amounts of residual N present in the root system or as immobilized N. Therefore, it was not possible to arrive at any definite conclusions related to the relative importance of roots in N immobilization. However, root N from 1983 microplots was determined separately.

Microplots removed in 1983

Forage yields of fescue during 1983 were 5,096 and 4,814 kg/ha for the broadcast and knife treatments, respectively. The adjacent unfertilized plot (not fertilized in 1982 or 1983) produced 4,408 kg forage /ha.

For both methods of application the total recovery of residual fertilizer N by tall fescue during 1983 was 2.7 kg N/ha or approximately 6 to 7% of the total residual N found in microplots removed during 1982. Similar low availability of residual fertilizer N has been reported by other researchers (Broadbent and Tyler 1962; Broadbent and Nakashima 1965; Allen et.al. 1973; Smith et.al. 1978). In those grass studies most of the residual N found as immobilized N became less available for plant uptake with time since N compounds of greater biological stability formed.

In the present study, amounts of residual N found during 1983 (table 4) were similar to those found in 1982 . A total of 35 kg N/ha (31% of the applied N) was measured in the entire soil profile where N was broadcast, 65% (22.6 kg N/ha) of which was in the 0-5 cm depth. A total of 37.5 kg residual N/ha was measured in the banded treatment, 44% (16.7 kg N/ha) of which was found near the depth of fertilizer placement (10-20 cm).

Most of the residual N found in microplots removed during 1983 was present as immobilized N. A total of 29.2 kg fertilizer N/ha were found immobilized in the broadcast treatment. More than half of this was measured in the top 5 cm of soil. The concentrations of immobilized N were relatively uniform from the 5 to 30 cm depth and decreased below 30 cm. Similar amounts of N were immobilized in the band treatment, 32.2 kg fertilizer N/ha, about half of which was in the 10 to 20 cm depth. The surface 10 cm had 12 kg N/ha of immobilized N and below the 20 cm depth concentrations decreased as in the broadcast treatment.

The tall fescue root system removed from the soil in 1983 contained 5.8 and 5.3 kg fertilizer N/ha in the broadcast and knife treatment respectively (about 5% of the applied N). In both cases most of the root N was measured in the top 5 cm of soil. This seems likely since about 65 to 70 % of the root dry matter was measured at this depth in both treatments.

Nitrogen Balance 1982-1983

Balances of N for microplots removed in 1982 and 1983 are shown in tables 5 and 6. As discussed earlier greater recoveries

Table 4. ROOT DRY MATTER AND FERTILIZER N REMAINING IN THE SOIL AT THE END OF 1983 GROWING SEASON. INORGANIC N WAS NOT DETERMINED.

	Broadcast N				Knifed N			
Depth	Root D.M	Root N	Immob N	Residual N	Root D.M.	Root N	Immob N	Residual N
cm	----------------------			kg/ha	----------------------			
0-5	8501	4.8	17.8	22.6	7847	3.8	7.1	10.9
5-10	1878	0.5	2.6	3.1	1314	0.6	4.9	5.5
10-20	1664	0.4	5.0	5.4	929	0.5	16.2	16.7
20-30	1198	0.1	2.5	2.6	963	0.4	2.4	2.8
30-60	—*	—	0.9	0.9	—	—	1.2	1.2
60-90	—	—	0.4	0.4	—	—	0.4	0.4
Total	13241	5.8	29.2	35.0	11053	5.3	32.2	37.5

*roots at these depths were not sampled.

Table 5. NITROGEN BALANCE FOR MICROPLOTS REMOVED IN 1982

Fate of Fertilizer N	Method of Application: Knife	Broadcast
	------------kg N/ha-----------	
Removed by plant tops (3 harvests)	61.2	41.2
Root & Immobilized N	39.1	36.2
Soil Inorganic	5.0	1.9
Total Recovered	105.3	79.3
Unaccounted For	6.7	32.7

Table 6. NITROGEN BALANCE FOR MICROPLOTS REMOVED IN 1983

Fate of Fertilizer N	Method of Application	
	Knife	Broadcast
	kg N/ha	
Removed by plant tops:		
1982 (3 harvests)	68.4	41.8
1983 (1 harvest)	2.7	2.7
Present in Roots	5.3	5.8
Immobilized	32.2	29.2
Total Recovered	108.6	79.5
Unaccounted For	3.4	32.5

of fertilizer N were obtained in 1982 harvests where N was knifed. Good duplication was obtained between microplots receiving the same treatment. For example, 61.2 and 41.2 kg N/ha was recovered in forage harvested from banded and broadcast microplots removed in 1982 (table 5); while 68.4 and 41.8 kg fertilizer N/ha was recovered in 1982 harvests from microplots removed in 1983.

Amounts of fertilizer N found as immobilized plus root N in 1982 are similar to those found in 1983. However, in 1983, 5.3 and 5.8 kg/ha of knifed and broadcast N was accounted for in roots; while forage harvested in both treatments contained 2.7 kg fertilizer N/ha. If these 1983 plant N contents (root and forage N) represent those found in 1982 roots plus that mineralized from 1982 organic N, we may assume that most of the residual N found in 1982 was present as immobilized N. Furthermore, this immobilized N seemed to mineralize slowly since only 2.7 kg N/ha was recovered in 1983 forage.

In 1982 soil inorganic N was low at 5.0 and 1.9 kg fertilizer N/ha respectively from knifed and broadcast treatments. Therefore, soil inorganic N determinations were not made in 1983 microplots.

During both years (1982 and 1983) approximately 94% of the knifed N and 71% of the broadcast N were recovered in plant and soil components. The fact that only 71% of the broadcast N (79.3 and 79.5 kg N/ha in 1982 and 1983, respectively) was accounted for indicates that N losses by ammonia volatilization and/or denitrification were of considerable significance in this treatment. Less than 6% of the knifed N (6.7 kg N/ha in 1982 and

3.4 kg N/ha in 1983) was unaccounted for in the knifed treatment indicating only small gaseous losses.

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CHAPTER 3
RESPONSE OF TALL FESCUE TO BROADCAST AND KNIFE N : PLANT N UPTAKE AND SOIL MINERAL N LEVELS OVER TIME

Abstract

The fate of knife (subsurface-banded) and broadcast fertilizer N applied to tall fescue (<u>Festuca arundinacea</u> Schreb) was determined by applying 0, 140, and 280 kg N/ha as UAN (28%N) to field plots during 1983 and measuring various components of the nitrogen balance throughout the growing season.

Analysis of the plots showed that broadcast N was taken up more readily early in the growing season and that knifed N became more available at latter stages of plant development. Inorganic N levels ($NH_4^+ + NO_3^-$ -N) decreased with time at a significantly faster rate in plots where N was broadcast compared to where N was knifed. At early stages of plant development 38% of the broadcast N (at 280 kg N/ha) was contained in grass tops and 33% in the roots, while only 9% was in the soil mineral form and 20% was unaccounted for. For knife treatments 23% was in the tops, 0% in the roots, 94% was mineral N and 0% was unaccounted for. Most of the broadcast N still remained in the root system by final harvest (approximately 36% of the applied N) while 39% was in theplant tops and 7% was present in the soil mineral form. Nearly 100% of the knifed N was accounted for during this time with 42% contained in plant tops and 58% present as mineral N.

In general, results obtained in this study suggest that the reduced N uptake observed in the broadcast treatment could be

partially due to the fact that a large part of the fertilizer N added is utilized and probably permanently immobilized by grass roots during early stages of plant development. The N unaccounted for in the broadcast treatment may have been immobilized by soil microorganisms or lost by gaseous means (NH_3 volatilization and/or denitrification). These processes seem to occur early in the season and may be the other important factors reducing N efficiency in the broadcast treatment.

Introduction

Previous research in Southeast Kansas has demonstrated a superiority of subsurface-band (knife) applications of NPK over broadcast applications of the same fertilizers (Lamond and Moyer 1983). The knife method of application gave significantly greater forage production, N concentration in forage and N uptake when compared to the broadcast method.

Recent research conducted in Southeast Kansas by Raczkowski and Kissel (1984) demonstrated that biological immobilization of N as well as gaseous losses (volatilization and denitrification) were major factors causing low recoveries of applied N on fescue. However, since similar amounts of knife and broadcast N were immobilized, it was concluded that the superiority of knife N over broadcast N might be due to reduced gaseous N losses obtained in the knife N treatments.

The study of Lamond and Moyer (1983) which indicated better fescue production from knife NPK applications, was carried out on the poorly drained clay pan soils of Southeast Kansas. The

present study was conducted on a deep, well drained, gently sloping soil with the following objectives: first, to evaluate the growth of fescue with time following broadcast and knife applications of N. Second, to evaluate the rate of available nitrogen dissappearance with time following knife and broadcast applications of N.

Materials and Methods

The study was conducted on a Smolan silty clay loam, a well drained, gently sloping deep soil that belongs to the fine montmorillonitic, mesic family of Pachic Argiustolls. This soil contained 12 ug/g available P, 322 ug/g exchangeable K^+, 3.2% O.M., a C.E.C. of about 220 mmol (+) kg-1 and a pH of 7.4 in the surface 15 cm.

Three rates of nitrogen (0, 140, and 280 kg N/ha) were applied as liquid urea-ammonium nitrate (UAN-28%N). This N carrier was either sprayed through flat fan-spray nozzles; or injected 15-20 cm deep with ammonia applicator shanks on 45 cm spacing. Triple superphosphate was broadcast on the surface of all plots at the rate of 35 kg of P/ha at the start of the experiment. Fertilizer solutions were metered through a positive displacement John Blue liquid fertilizer pump driven from the ground-speed dependent power take-off on a Massey Ferguson 265 tractor. Plots (2.5 m by 10 m) were fertilized on March 18, 1983 while the fescue was dormant. Soil and plant material were collected throughout the growing season. Table 1 gives the dates and components sampled during the study.

TABLE 1. DATES WHEN SOIL AND PLANT SAMPLES WERE COLLECTED DURING THE STUDY.

DATE	COMPONENTS SAMPLED
March 18*	___
March 28	soil
April 29	soil and plant tops
May 9	soil, roots and plant tops
May 31	soil and plant tops
June 17	soil, roots and plant tops

* Treatments were applied.

The experimental design selected was split-plot with three replications; the whole-plot treatments (N rate X method of N application combinations) were arranged as randomized complete blocks while the subplot variables (time of sampling within a whole plot) were completely randomized.

Grass from a 0.675 m^2 area (135 cm by 50 cm) was hand harvested from the center of each plot. Where N was knifed the area harvested contained the three center bands in the plot. Plants were clipped close to the ground from areas not previously harvested. Grass clippings were dried in a forced air oven at a temperature of 65 C, weighed, ground in a wiley mill to pass through a 1 mm screen and stored in sealed, plastic vials for later N determination.

Soil samples were collected from plots receiving the high rate of N on four occasions during plant development. Where N was broadcast six core samples of 2.5 cm in diameter were removed from the harvested area in 10 cm increments from the surface 30 cm and 30 cm increments between 30 and 90 cm. Where N was knifed, the surface 30 cm of soil were sampled by removing the entire soil from an area 45 cm wide by 20cm long centered over each of the three center bands (bands were 45 cm apart) in the harvested area. Soil sections were removed in ten cm increments to a depth of 30 cm. Six core samples were taken at 30 cm increments between 30 and 90 cm. Soil samples were dried in a forced-air oven at 45 C, finely ground and stored for determination of NH_4^+ and NO_3^--N.

Root samples were collected twice during plant development from plots receiving the 0 kg N/ha and 280 kg N/ha broadcast

treatments. A 10 cm diameter core of soil was collected from each plot and sectioned into increments of 10 cm from the surface 30 cm. Roots were washed free of soil, dried at 65 C, weighed and stored in plastic vials for later N analysis.

For nitrogen analysis, plant samples were digested using a modification of the salicylic acid-thiosulfate procedure described by Bremner and Mulvaney (1983). Soil samples were extracted with KCl and the NO_3^- and NH_4^+-N determined. Nitrogen concentrations (plant and soil NO_3^- + NH_4^+ -N) were measured colorimetrically on a dual-channel Technicon Autoanalyzer.

Results and Discussion

Mean forage yields by fescue for both methods of N application is given in table 2. Interaction effects (N method X rate, and N method X rate X time) were not significant (table 3). In general, yield differences in the study between knife and broadcast methods of N application were significant with broadcast N yielding highest.

Forage production during the study is given in table 4. Application of N increased forage yield with both methods of application. Although not statistically significant, at the lower rate of N application the production of dry matter was greater in those plots which received the broadcast treatments. At the higher rate of N application the production of dry matter in plots receiving the broadcast treatment became significantly greater during the latter part of the growing season.

Significant interaction effects (N method X time, N method X

TABLE 2. MEAN FORAGE YIELD BY TALL FESCUE DURING THE STUDY

METHOD	YIELD
	kg/ha
Knife	4057
Broadcast	4361
LSD(.05)	286

TABLE 3. SIGNIFICANCE OF F-TESTS PERFORMED OVER METHOD, RATE AND TIME MAIN EFFECTS AND THEIR INTERACTIONS

Treatments	Variable		
	% N	Yield	N uptake
Method	NS	*	NS
Rate	*	*	*
Time	*	*	*
Method X Rate	NS	NS	NS
Method X Time	*	NS	*
Rate X Time	*	*	*
Method X Rate X Time	*	NS	NS

* Indicates significance at 0.05 level of probability.

TABLE 4. DRY MATTER PRODUCTION AT FOUR DATES DURING THE GROWING SEASON AS AFFECTED BY BROADCAST (BC) OR KNIFED (KN) FERTILIZER N.

N Rate	April 29 BC	April 29 KN	May 9 BC	May 9 KN	May 31 BC	May 31 KN	June 17 BC	June 17 KN
				FORAGE YIELDS				
				kg/ha				
0	1199	1495	1325	1452	2658	2885	4179	4302
140	2291	1790	3180	3023	6440	5720	7672	7296
280	2743	3043	3577	2941	7304	6067	9764	8667
LSD(.05)*				822				

*To compare means within same date.

time X rate) occurred for percent N in forage (table 2). Interaction effect method X time was significant for N uptake. Therefore, the data on percent N and N uptake by the forage will be discussed taking these intearctions into consideration.

At the early stages of growth, percent N was significantly greater from broadcast N applications (table 5). At later stages of growth, forage %N became greater in the knife treatments. The same trend was observed for N uptake by the forage (table 6), but comparisons between treatments were seldom significant. This data indicates that broadcast N is more available for uptake early in the season while knifed N becomes more available at later stages of plant development. The superiority of broadcast N to knife N early in the season may be explained by two factors: first, broadcast N is applied to an extensive root mass that allows rapid assimilation. Second, soil temperatures are higher near the soil surface which enhances root absorption of N.

During the late stages of plant development forage N concentration and N uptake became greater in the knife treatments. However, in these treatments dry matter yields were significantly lower than when N was broadcast. This may be explained by the uneven forage growth observed in the knife treatments. Since fertilizer N was placed in bands, plants growing directly over the bands grew larger than plants between bands. Thus, a wavy pattern of growth was created indicating N deficiency of plants between bands, thereby reducing overall forage yield. Fertilizer N levels (NO_3 + NH_4^+-N) to a depth of 90 cm with time are given in figure 1. Fertilizer N levels

TABLE 5. FORAGE N CONCENTRATION AT FOUR DATES DURING THE GROWING SEASON AS AFFECTED BY BROADCAST (BC) OR KNIFED (KN) FERTILIZER N

	NITROGEN CONCENTRATION							
	April 29		May 9		May 31		June 17	
N Rate	BC	KN	BC	KN	BC	KN	BC	KN
kg/ha	---------------------%N---------------------							
0	1.85	2.15	1.71	1.92	1.16	1.27	.85	.96
140	2.92	2.54	2.75	3.00	1.53	1.86	1.05	1.38
280	3.50	2.78	3.70	3.20	2.20	2.47	1.48	1.82
LSD(.05)*	0.38							

*To compare means within the same date.

TABLE 6. N UPTAKE AT FOUR DATES DURING THE GROWING SEASON AS AFFECTEDBY BROADCAST (BC) OR KNIFED (KN) FERTILIZER N

	NITROGEN UPTAKE							
	April 29		May 9		May 31		June 17	
N Rate	BC	KN	BC	KN	BC	KN	BC	KN
--------kg N/ha--------								
0	22	32	26	28	31	37	36	41
140	67	45	87	90	99	106	80	103
280	96	86	133	93	161	150	145	158
LSD(.05)*				23				

*To compare means within the same date.

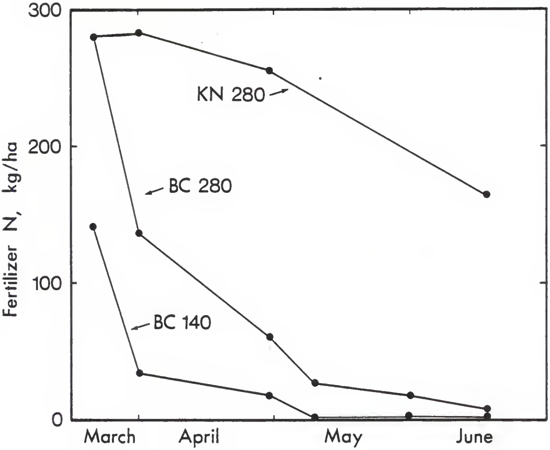

Fig. 1-Fertilizer N (inorganic N in treatment plot - inorganic N in check plot) in the top 90cm of soil following knifed (at 280 kgN/ha) and broadcast (at 140 and 280 kgN/ha) applications of N on March 18.

decreased with time at a significantly faster rate in plots where N was broadcast compared to where N was knifed. Where N was knifed at 280 kg N/ha significant amounts of inorganic N remained in the soil at the end of the growing season.

Surprisingly, ten days after treatments were applied on March 28 only 49% of the applied N was accounted for as inorganic N in the 280 kg N/ha broadcast treatment. About 25% of the applied N remained as inorganic N on the broadcast 140 kg N/ha treatment. At this time no spring growth had yet occurred. This led us to believe that much of the unaccounted N could be present in roots.

Roots were sampled on May 9 and June 17 from the unfertilized plots and from plots which received 280 kg N/ha broadcast. At each depth sampled, root N content was nearly always significantly higher in fertilized plots (table 7). Approximately 33% (92 kg N/ha) of the broadcast N was accounted for in root samples on May 9. Of this N present in roots 78% (72 kg N/ha) was in the surface 10cm layer. Much of the applied N still remained in the surface 10 cm of roots by final harvest (june 17). Approximately 36% (100 kg N/ha) of the broadcast N was accounted for in roots during this time suggesting that little if any of the N utilized by roots early in the season was translocated to grass tops.

Grasses are known to have a very extensive root system. In working with several grass species Power (1980) found that generally the root biomass was 10 to 20 times greater than the annual above-ground dry matter production depending upon the grass species studied and the amount of N applied. Kissel and

TABLE 7. NITROGEN CONTENT OF GRASS ROOTS FROM PLOTS RECEIVING 280 kg N/ha BROADCAST AND THE UNFERTILIZED PLOTS (CHECK)

Depth	MAY 9 B'cast	MAY 9 Control	MAY 9 Fert. N	JUNE 17 B'cast	JUNE 17 Control	JUNE 17 Fert. N
cm			kg N/ha			
0-10	282_a*	210_b	72	378_a	283_b	95
10-20	56_a	44_b	12	41_a	38_a	3
20-30	18_a	10_b	8	10_a	8_a	2
Total	356_a	264_b	92	429_a	329_b	100

*within a given depth means with the same letter are not significantly different at the 5% level using Fisher's LSD.

Smith (1978) reported root dry matter weights of 12,771 kg/ha for coastal bermudagrass while up to 24,310 kg/ha of root material was reported by Black and Wight (1979) for native grassland herbage. Other researchers have reported similar root yields (Blue 1970; Ogus and Fox 1970; Power 1972; Power and Alessi 1971).

In the present study, the unfertilized check contained 25,504 kg/ha of root dry matter in the top 30 cm of soil. The fertilized grass (with 280 kg N/ha broadcast) yielded 27,310 kg/ha of root dry matter which by harvest time contained 100 kg/ha more N than did the check. This suggests that the below-ground root system was a N deficient sink which by virtue of it's large mass utilized and immobilized relatively large amounts of fertilizer N. Power and Alessi (1971) recognized this utilization of N by roots as an important factor contributing to the low amount of N recovered in grass tops. They concluded that in order to obtain maximum forage growth. The root systems nitrogen requirement must be satisfied, a process that could require several years. There is also evidence that much of the N taken up by roots could remain there for long periods of time. In a long term grass study, Power (1983) estimated 70 to 160 kg fertilizer N/ha still immobilized in the root biomass, 5 years after fertilization had ceased.

Fescue crowns were not analyzed separately in this study but were included with the surface 10 cm root samples. Therefore, some of the fertlizer N accounted for in roots from the 0 to 10 cm depth was present as crown N.

Nitrogen Balance

Nitrogen balances obtained for the high N rate (280kg N/ha) treatments on May 9 and June 17 are shown in table 8. Inorganic N levels from fertrilizer in the knife treatments were always high compared to broadcast treatments. More than half of the applied N (162 kg N/ha) was still present as inorganic N at plant maturity (June 17) in the knife treatments. For comparison, levels of inorganic N in the broadcast treatments were 27 kg N/ha by May 9. Most of the broadcast N not found in the inorganic form was assimilated by the grass. For example, on May 9 the addition of plant top and root N was 71% of the N applied (107 + 92 = 199 kg N/ha). Nearly the same root and plant top N contents were estimated on June 17 (109 and 100 kg fertilizer N in plant tops and roots, respectively) indicating that most of the N absorbed by roots early in the season remained as root N and very little if any translocated to plant tops.

For the knifed treatment at 280 kg N/ha, the sum of fertilizer N in plant tops and soil inorganic N on May 9 was 319 kg N/ha or 114% of the applied N. On June 17th 100% (118 + 162 = 280kg N/ha) was accounted for in these components. Since nearly 100% of the fertilizer N was accounted for as soil inorganic N and plant uptake, we can assume that roots utilized very little, if any, of the knife N. This seems possible since less root mass is in contact with the applied N in the knife treatments compared to roots in the broadcast treatments. Roots over and around the band absorb and utilize some of the applied N to meet plant requirements, but the majority of the available N still remain in

TABLE 8. NITROGEN BALANCE AT TWO DATES DURING THE GROWING SEASON FOR PLOTS RECEIVING KNIFE OR BROADCAST APPLICATIONS OF 280 kg N/ha.

Components	Fertilizer N			
	May 9		June 17	
	KN	BC	KN	BC
	------------kg N/ha-------------			
Plant tops	65	107	118	109
Soil inorganic N	264	27	162	19
Root N	*	92	*	100
TOTAL	319	226	280	228
%RECOVERED	114	80	100	81

*Roots were not sampled.

the soil for further uptake during the latter part of the season. In the broadcast treatment a greater percentage of the applied N is utilized by roots and probably incorporated permanently in their cellular components.

In the broadcast treatments approximately 81% (228 kg N/ha) of the applied N was accounted for as plant (roots and tops) and soil inorganic N. There was no evidence in the soil inorganic N data of N leaching, no runoff was evident, and, presumably, ammonium fixation was negligible. Therefore, fertilizer N from the broadcast treatment not accounted for in plant tops and roots by uptake in top growth, utilization by roots, or remaining as soil inorganic N was either immobilized by soil microorganisms and/or lost from the soil-plant system in gaseous forms (NH_3 volatilization and/or denitrification). Whichever mechanism was involved the loss may have occurred early in the growing season since inorganic N levels showed the fastest rate of depletion during that time.

General Discussion

Results obtained in this study suggest that broadcast N is readily available for uptake early in the season while N knifed to a depth of 15-20 cm is less available but becomes more available for plant use later in the season. Grass roots absorb much more N than needed early in the season on broadcast treatments. In addition, soil temperatures are higher near the soil surface which enhances root absorption of N. More root mass is exposed to the applied N in broadcast applications; thererore, greater plant uptake is likely to occur in these treatments

during the early stages of plant development. This may be explained by the following: first, where the N is knifed less root mass is in contact with the applied N. Roots around the band absorb some of this N but the majority of the available N still remains in the soil for further uptake during the latter part of the season. The N taken up by the roots in broadcast treatments may partially explain why inorganic N levels decreased with time at a significantly faster rate compared to where N was knifed. The N unaccounted for in broadcast treatments may have been immobilized by soil microorganisms or lost by gaseous means (NH_3 volatilization and/or denitrification). These processes seem to occur early in the season and may be the other important factors reducing N efficiency in the broadcast treatments.

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FATE OF SUBSURFACE BANDED (KNIFE) AND BROADCAST N APPLIED TO TALL FESCUE (*Festuca arundinacea* Schreb)

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The purpose of the studies presented in this thesis were the following: First, to determine why N uptake and forage production by tall fescue (Festuca arundinacea Schreb) in Southeast Kansas are higher from knifed than from broadcast applications of N. Second, to follow N transformations under established tall fescue after addition of N using broadcast and knife methods of N application.

In the first study, the fate of N fertilizer applied to fescue was determined either broadcast or banded in 1982 using ^{15}N tagged UAN solution and measuring various components of the N balance. Plant uptake of residual N was measured during 1983. Fifty eight percent of the applied N was recovered in harvested forage in 1982 where N was knifed; while only 37% was recovered in broadcast treatments. The amount of N remaining in the soil as residual N at the end of 1982 amounted to 34% and 39% for broadcast and knifed treatments respectively. Most of this residual N was not available the following year since only about 6 to 7% was recovered in the forage. About 6% of the knifed N was unaccounted for indicating that gaseous losses (denitrification and ammonia volatilization) were no more than 6% of the applied N; while up to 29% of the broadcast N was uanccounted for, indicating probable significant gaseous losses. Similar results were obtained from microplots removed during 1983. In general, results obtained in this study suggest that the improved efficiency of knifed N over broadcast N observed in Southeast Kansas in past years may be explained by the reduced gaseous N losses obtained in this treatment.

Nitrogen transformations under established tall fescue were

followed in the second study by applying 0, 140 and 280 kg N/ha as UAN (28% N) to field plots during 1983 and measuring various components of the N balance throughout the growing season. Analysis of the plots showed that broadcast N was taken up more readily early in the growing season and that knifed N became more available at later stages of plant development. Inorganic N levels ($NH_4^+ + NO_3^-$ -N) decreased with time at a significantly faster rate in plots where N was broadcast compared to where N was knifed. At early stages of plant development 38% of the broadcast N (at 280 kg N/ha) was contained in grass tops and 33% in the roots, while only 9% was in the soil mineral form and 20% was unaccounted for. For knife treatments 23% was in tops, 0% in roots, 94% was mineral N and 0% was unaccounted for. Most of the broadcast N still remained in the root system by final harvest (approximately 36% of the applied N) while 39% was in plant tops and 7% was present in the soil mineral form. Nearly 100% of the knife N was accounted for during this time with 42% contained in plant tops and 58% present as mineral N.

In general, results obtained in this study suggest that the reduced N uptake observed in the broadcast treatment could be partially due to the fact that a large part of the fertilizer N added is utilized and probably permanently immobilized by grass roots during early stages of plant development. The N unaccounted for in the broadcast treatment may have been immobilized by soil microorganisms or lost by gaseous means (NH_3 volatilization and/or denitrification). These processes seeem to occur early in the season and may be the other important factors reducing N efficiency in the broadcast treatment.